SATELLITE EHF COMMUNICATION DESIGN CONSIDERATIONS DUE TO ATTENUATION BY RAIN

BY: Paul Tattelman, Air Force Geophysics Laboratory, Hanscom AFB, MA 01731

Mr. Tattelman is a research meteorologist with the Atmospheric Sciences Division of the Air Force Geophysics Laboratory, Hanscom AFB, MA. He has been employed there since 1967, except from 1969 to 1971 when he served as a Weather Officer in the Navy. He received the B.S. degree in meteorology from the Pennsylvania State University in 1967 and has done postgraduate work in meteorology, statistics, and management. He is currently responsible for planning, conducting, and managing applied research programs to determine probability distri-)utions of atmospheric conditions. Results are)rimarily used for the design, testing, and oper-tion of systems affected by weather. He was hairman of the triservice (Army, Navy, and Air orce) committee that developed MIL-STD-210C, limatic Information to Determine Design and Test quirements for Military Systems and Equipment." has published over 40 papers in applied climatology, and has provided consultation to many Federal agencies and their contractors.

Abstract

The increasing use of Extra High Frequencies (EHF) planned for satellite communications has prompted studies on the impact of signal attenuation by rain. Rain is the major environmental cause of communication outages at frequencies above 10GHz. One-minute rainfall rates are considered to be the most practical time-averaged rate for use in attenuation models to estimate outages. Data on one minute rain rates are very scarce, but a new data set of these rates was extracted for a 10-year period at 42 U.S. locations. This paper presents analyses of the duration and frequency of one-minute rain rates, their impact on EHF communications, and resulting design considerations.

1. Introduction

Attenuation due to rain is the major environmental cause of outages to satellite communication systems employing EHF(Extremely High Frequencies). Attenuation models have been developed to calculate the impact of rain on these systems based on rain rate distributions (e.g. Crane[1]) One-min rain rates are recognized as most practical for these path attenuation calculations, but data on 1-min rates are scarce. This has prompted the development of models for estimating 1-min rain-rate distributions (Tattelman and Scharr[2], Tattelman and Grantham[3]).

Attenuation of EHF signals can be significant at relatively low rain rates that occur with varying probabilities just about anywhere in the world. Therefore, more precise rain-rate data are required for locations representing many climatic rainfall regimes. With this in mind, Tattelman and Knight[4] describe a method for extracting and digitizing 1-min rain rates from original analog raingage recordings. The method employs modern digitizing and filtering techniques to obtain the 1-min data that are ordinarily unreadable by eye. This method was used to extract the rain data analyzed in this article.

2. Analyses of One-Minute Rates

Weighing raingage recordings for approximately 300 U.S. weather stations are archived on microfiche at the National Climatic Data Center (NCDC), Asheville, North Carolina. Ten years of 1-min rainrate data for 42 locations chosen to represent a variety of climatic rainfall regimes were analyzed. The locations and the percent of time it rained at each is provided in Table 1 (note: only 6 1/2 years of data were available at San Sebastian, PR).

Table 1. Locations for which 1-min rain-rate data were studied and the percent of time it rained.

Location	Elevation (m)	Percent of Time it Rains Jan	Apr	Jul	Oct	Ann
Aberdeen, SD	395	2.0	5.0	2.1	3.2	2.9
Albuquerque, NM	1619	1.9	0.9	1.9	2.0	1.5
Allentown, PA	118	9.5	6.6	4.0	5.9	6.8
Asheville, NC	652	7.2	4.4	4.1	5.6	5.9
Bakersfield, CA	145	2.1	1.2	<.1	0.6	1.4
Billings, MT	1087	5.4	6.4	1.6	4.4	4.0
Boise, ID	865	6.8	3.3	0.8	2.8	3.2
Boston, MA	5	8.7	6.6	3.1	5.4	6.3
Cape Hatteras, NC	2	6.4	3.5	4.3	4.9	5.0
Charleston, SC	12	6.1	2.7	4.1	2.4	4.3
Cheyenne, WY	1867	1.6	4.2	2.3	2.1	2.6
Chicago, IL	185	6.0	6.6	2.8	4.5	5.2
Denver, CO	1610	1.7	4.6	1.9	2.6	2.8
Ely, NV	1906	2.2	3.3	1.6	2.6	2.3
Grand Junction,CO	1475	2.8	2.1	0.8	2.2	1.8
Houston, TX	29	6.3	3.3	2.5	3.3	3.7
Huntsville, AL	190	8.1	4.5	3.3	4.0	5.0
Internat'l Falls,MN	359	4.1	4.3	3.8	5.0	4.3
Key West, FL	3	1.8	1.0	2.6	2.8	2.3
Lexington, KY	294	9.4	6.9	4.2	5.7	6.4
Miami, FL	2	1.9	1.6	3.3	3.9	3.1
Newark, NJ	2	8.8	5.7	3.6	5.2	6.1
New Orleans, LA	1	5.8	3.3	4.5	2.2	4.1
New York, NY	4	8.0	6.1	3.1	5.0	5.9
Oklahoma City, OK	1285	2.3	3.1	2.5	3.9	3.0
Omaha, NE	300	2.8	5.4	2.8	4.2	3.7
Philadelphia, PA	2	8.7	6.3	3.3	5.2	5.7
Phoenix, AZ	340	1.5	0.4	0.6	1.6	1.0
Pittsburg, PA	228	8.6	5.4	3.6	5.5	5.6
Raleigh, NC	132	7.1	4.1	3.6	4.5	5.0
Rapid City, SD	965	2.1	5.8	2.6	2.6	3.0
San Angelo, TX	580	1.6	1.8	1.6	3.0	1.9
St. Louis, MO	163	5.0	4.8	2.4	3.7	4.3
San Sebastian, PR	260	0.9	1.6	1.5	2.0	1.8
Santa Maria, CA	72	4.2	1.4	<.1	0.8	1.8
Seattle, WA	120	14.0	6.5	2.3	7.3	8.1
Shreveport, LA	77	7.4	3.7	3.3	3.5	3.9
Spokane, WA	718	8.5	3.2	1.4	2.7	4.4
Tallahassee, FL	17	6.7	3.0	5.2	2.5	4.3
Topeka, KS	267	3.0	4.7	2.8	4.0	3.8
Urbana, IL	175	4.7	4.1	2.7	3.6	4.1
Yuma, AZ	59	1.0	0.2	0.1	0.7	0.4

The analyses of 1-min rates presented here are intended primarily to assess the impact of rain on EHF satellite communications. Most previous studies of short-duration rain rates for use in attenuation models provide data in the form of annual rain-rate frequencies-of-occurrence (Tattelman and Grantham[3]). However, annual statistics can be very misleading because critical rates, (rain rates that would cause an outage) are concentrated in only a few months of the year at most locations. A low annual frequency of occurrence of a critical rain rate can be intolerably high in these months. Monthly or seasonal rain-rate statistics are preferable for assessing the impact of attenuation caused by rain.

3. Rain-Rate Intensities and Durations

Monthly average number of occurrences versus rain rate for six different duration times are provided for the worst (most extreme) month at New Orleans (August) in Figure 1. New Orleans has one of the heaviest rain-rate regimes of all the locations studied. The worst month was chosen to generally represent the highest number of occurrences of rain rates for all durations. Occurrences for some rates and durations may be higher in other months. Figure 2 shows average occurrences of 1-min rates for mid-season months at Boston to provide an appreciation of seasonal variations. Figure 3 shows how rain-rate intensities vary across the United States based on the 42 locations studied. This figure shows rain rates occurring for a 5-minute duration with a 0.1 probability of at least 3 occurrences during the worst month.

4. Outage Estimates

Ordinarily, attenuation models are used to determine path attenuation given the point rain rate. For this exercise, we reversed the order of calculation by determining critical rain rates that would cause an outage for a specified total path attenuation of 15 dB at 15, 30, and 45 GHz. The USAF Environmental Technical Applications Center (USAFETAC), Systems Support Section, provided critical rain rates based on the model developed by Crane[1]. Path length through the rain was determined using long-term average monthly freezing levels derived by USAFETAC. Attenuation due to ice and snow above the freezing level is minimal.

Rain intensities are generally highest during the summer months when freezing levels are also at their highest; thus, the number of outages is greatest during these months. The highest critical rain rates are at locations with the lowest freezing levels above the ground (other factors being equal). Freezing levels generally decrease with increasing latitude and station elevation. The rain-rate distributions and the critical rates were used to determine the worst month for attenuation outages at each location. An analysis of the worst month for the U.S., based on the results, is shown in Figure 4.

The mean percent of time in the worst month with system outages is provided in Table 2 for propagation path elevation angles of 10, 30, 50, and 70 degrees. An examination of Table 2 reveals that outages due to rain are relatively infrequent on a percentage of time basis. At 45GHz, availabilities are at least 94.3% at all locations

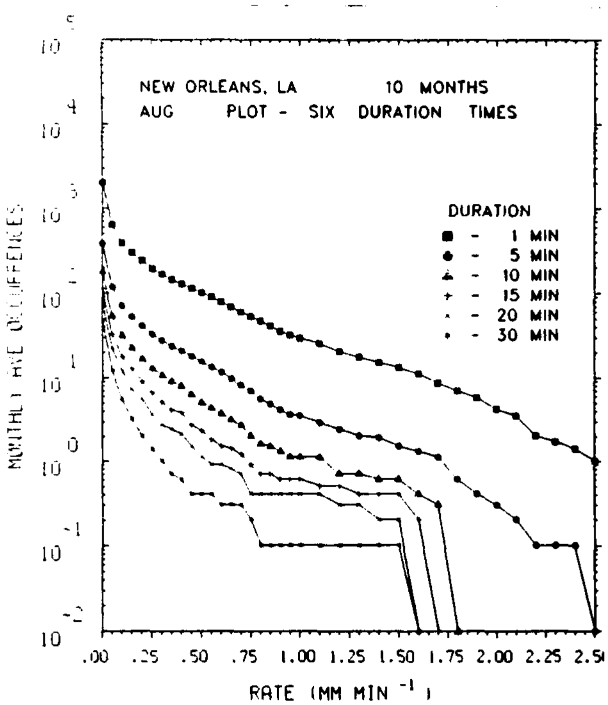

Figure 1 Monthly average number of occurrences versus rain rate for six duration times during August at New Orleans

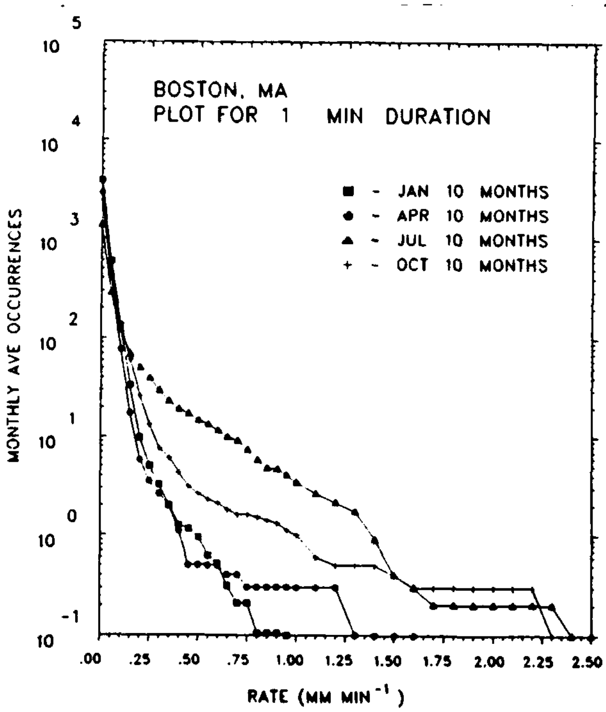

Figure 2 Average number of occurrences of 1-min. rain rate for mid-season months at Boston

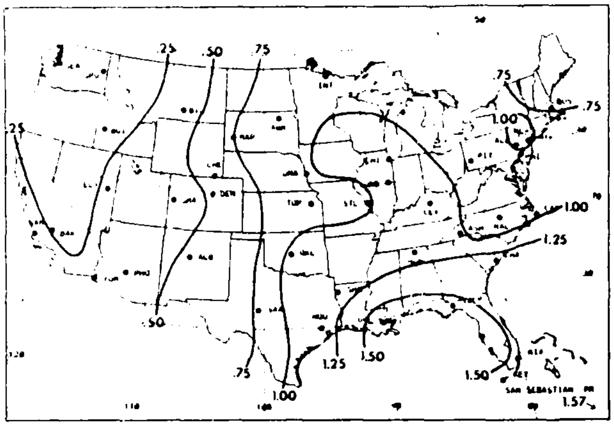

Figure 3 Rain rates (mm/min) for a 5-minute duration with a 0.1 probability of at least 3 occurrences during the worst month

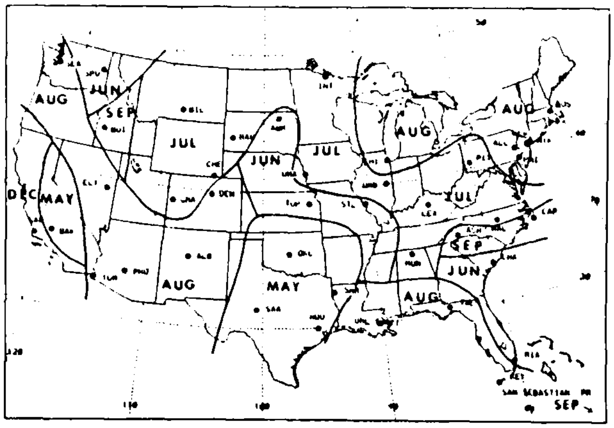

Figure 4 Worst months for attenuation outages

Table 2

Estimated Mean Percent of the Time With System Outages Due to Rain in the Worst Month for Stated Elevation Angles (Based on the Frequencies and Fade Margins Listed Below).

Percent of time in the Month

		15 GHz 15 dB Elevation Angle (in degrees)				30 GHz 15 dB Elevation Angle (in degrees)				45 GHz 15 dB Elevation Angle (in degrees)			
Location	Month(s)	10	30	50	70	10	30	50	70	10	30	50	70
Aberdeen, SD	JUN	0.10	0.03	0.01	0.01	1.23	0.21	0.14	0.10	2.92	0.58	0.26	0.17
Albuquerque, NM	AUG	0.04	0.01	0.01	0.00	0.70	0.09	0.06	0.04	1.79	0.23	0.10	0.07
Allentown, PA	AUG	0.19	0.07	0.03	0.01	3.34	0.52	0.32	0.21	4.52	1.40	0.74	0.40
Asheville, NC	SEP	0.09	0.03	0.01	0.01	4.09	[illegible]	0.19	0.10	5.69	1.46	0.69	0.27
Bakersfield, CA	MAY	0.01	0.00	0.00	0.00	0.29	0.02	0.01	0.01	0.56	0.04	0.03	0.02
Billings, MT	JUL	0.02	0.00	0.00	0.00	0.20	0.04	0.02	0.01	1.24	0.11	0.04	0.03
Boise, ID	SEP	0.01	0.00	0.00	0.00	0.18	0.01	0.01	0.01	1.28	0.07	0.02	0.01
Boston, MA	AUG	0.09	0.03	0.02	0.01	3.30	0.33	0.15	0.10	4.59	1.02	0.40	0.22
Cape Hatteras, NC	SEP	0.21	0.08	0.04	0.03	3.14	0.53	0.36	0.26	4.39	1.39	0.65	0.44
Charleston, SC	JUN	0.33	0.13	0.08	0.06	3.07	0.73	0.48	0.37	4.10	1.49	0.87	0.62
Cheyenne, WY	JUL	0.05	0.01	0.00	0.00	0.48	0.12	0.07	0.05	1.90	0.34	0.15	0.09
Chicago, IL	AUG	0.15	0.06	0.04	0.03	2.56	0.38	0.24	0.17	3.52	0.92	0.53	0.29
Denver, CO	AUG	0.04	0.01	0.01	0.01	0.67	0.10	0.06	0.04	1.50	0.28	0.12	0.07
Ely, NV	AUG	0.01	0.00	0.00	0.00	0.15	0.02	0.01	0.01	1.09	0.07	0.03	0.02
Grand Junction, CO	JUL	0.01	0.01	0.01	0.00	0.23	0.02	0.02	0.01	0.68	0.07	0.03	0.02
Houston, TX	MAY	0.24	0.09	0.05	0.04	2.56	0.62	0.39	0.28	3.24	1.47	0.84	0.49
Huntsville, AL	JUL	0.27	0.11	0.07	0.05	2.46	0.62	0.41	0.31	3.27	1.37	0.74	0.51
Internat'l Falls, MN	JUL	0.08	0.03	0.01	0.01	2.01	0.19	0.12	0.08	3.35	0.65	0.27	0.15
Key West, FL	AUG	0.27	0.14	0.09	0.07	2.55	0.61	0.41	0.32	3.56	1.38	0.75	0.51
Lexington, KY	JUL	0.24	0.11	0.06	0.04	3.04	0.53	0.37	0.27	4.12	1.20	0.70	0.43
Miami, FL	JUN	0.38	0.18	0.12	0.10	3.41	0.79	0.57	0.45	4.62	1.92	1.05	0.71
Newark, NJ	AUG	0.15	0.06	0.03	0.03	2.96	0.44	0.23	0.17	4.02	1.33	0.60	0.31
New Orleans, LA	AUG	0.38	0.19	0.11	0.08	3.25	0.85	0.60	0.45	4.43	1.95	1.07	0.73
NYC (Kennedy), NY	AUG	0.11	0.04	0.03	0.02	2.56	0.32	0.18	0.13	3.56	1.03	0.43	0.25
Oklahoma City, OK	MAY	0.15	0.04	0.02	0.01	2.12	0.45	0.24	0.15	3.85	1.30	0.57	0.32
Omaha, NE	JUL	0.12	0.05	0.03	0.02	2.01	0.30	0.19	0.14	2.74	0.87	0.43	0.22
Philadelphia, PA	AUG	0.19	0.07	0.04	0.02	2.60	0.50	0.31	0.24	3.48	1.25	0.63	0.40
Phoenix, AZ	AUG	0.03	0.01	0.01	0.01	0.47	0.06	0.04	0.03	0.66	0.20	0.08	0.05
Pittsburgh, PA	JUL	0.11	0.04	0.03	0.02	2.02	0.30	0.16	0.12	3.44	0.90	0.40	0.22
Raleigh, NC	JUL	0.16	0.05	0.02	0.01	2.54	0.47	0.29	0.19	3.55	1.21	0.57	0.37
Rapid City, SD	JUL	0.05	0.02	0.01	0.01	1.28	0.12	0.07	0.05	2.33	0.32	0.16	0.09
St. Louis, MO	JUN	0.13	0.05	0.03	0.02	1.53	0.33	0.19	0.14	2.53	0.74	0.38	0.24
San Angelo, TX	MAY	0.07	0.03	0.02	0.01	1.11	0.14	0.10	0.07	1.77	0.46	0.21	0.12
San Sebastian, PR	SEP	0.43	0.18	0.12	0.09	2.85	0.87	0.63	0.49	3.77	1.67	1.07	0.78
Santa Maria, CA	DEC	0.02	0.00	0.00	0.00	1.28	0.10	0.04	0.02	3.13	0.49	0.17	0.06
Seattle, WA	AUG	0.01	0.00	0.00	0.00	1.68	0.02	0.01	0.01	3.11	0.29	0.05	0.01
Shreveport, LA	MAY	0.21	0.07	0.03	0.02	2.07	0.55	0.34	0.30	3.19	1.13	0.68	0.44
Spokane, WA	JUN	0.02	0.00	0.00	0.00	0.26	0.03	0.02	0.01	1.65	0.08	0.04	0.03
Tallahassee, FL	AUG	0.44	0.23	0.15	0.11	3.65	0.92	0.65	0.51	4.99	2.17	1.17	0.78
Topeka, KS	JUN	0.15	0.06	0.03	0.02	2.22	0.37	0.22	0.16	3.70	1.01	0.47	0.29
Urbana, IL	JUL	0.25	0.12	0.08	0.06	1.92	0.52	0.36	0.28	2.48	1.13	0.63	0.43
Yuma, AZ	AUG	0.02	0.01	0.00	0.00	0.35	0.07	0.04	0.03	0.48	0.20	0.09	0.06

studied. This increases to 96.3% at 30 GHz and 99.5% at 15 GHz. To put the true impact of rain, attenuation into perspective, it should be noted that each minute of rain is not randomly distributed in a month. When it is raining hard enough to cause an outage, it is likely to persist for a period of time. The duration of precipitation events causing outages deserves special attention for EHF satellite comunications.

Table 3 provides the mean number of system outages due to rain in the worst month with durations of 5, 10, 20, and 30 minutes at a frequency of 30 GHz and a fade margin of 15 dB. From the table it can be seen that a large number of outages for extended period can be expected at most locations.

Table 4 provides the probabilities of at least 3 attenuation outages for all months at Boston for a frequency of 30 GHz and fade margins of 15, 20, and 25 dB. The profound influence of the elevation angle on the number of outages is evident in Tables 2 and 3. Table 4 provides a good example of how outages due to rain are most likely during the summer months when rain intensities and freezing levels are highest.

5. Conclusions

This study shows the profound influence of propagation path elevation angle on the quantity and duration of outages. Low elevation angles greatly increase the path length through the rain. Total path attenuation is also greatly influenced by the height of the freezing level, above which the attenuation from ice and snow is negligible. Rain rates and freezing levels are generally much lower during the winter months, thereby minimizing the liklihood of an outage. Design of satellite EHF communications should be based on conditions during the month of the year when the probability and duration of outages is greatest. This is usually a summer month when rain rates and freezing levels are usually highest. Annual statistics that inclue the very low outage-probability winter months conceal the real impact of rain attenuation on operations.

The data from this study can be used to develop a general strategy for minimizing the impact of attenuation due to rain. Since rain attenuation is minimal at most middle and northern latitude locations during the coldest half of the year, a satellite should be positioned to keep propagation path elevation angles highest in the subtropics and tropics. During the summer months when attenuation due to rain at mid and high latitudes is generally greatest, a switch to lower frequencies and/or higher power levels may be needed to increase system availability. Rain outages during the summer months are least likely

Table 3

Estimated Mean Number of System Outages Due to Rain in the Worst Month for the Indicated Durations (Based on a Frequency of 30 GHz and a Fade Margin of 15 dB).

NUMBER OF OUTAGES

Location		5-min Duration, Elevation Angle (in degrees)				10-min Duration, Elevation Angle (in degrees)				20-min Duration, Elevation Angle (in degrees)				30-min Duration, Elevation Angle (in degrees)			
		10	30	50	70	10	30	50	70	10	30	50	70	10	30	50	70
Aberdeen	JUN	101.2	16.7	10.6	7.3	47.9	7.1	4.2	2.8	21.7	2.4	1.2	0.8	12.1	0.8	0.5	0.3
Albuquerque	AUG	58.4	6.5	4.6	3.1	26.8	2.7	1.6	0.8	11.7	0.8	0.6	0.2	6.5	0.3	0.0	0.0
Allentown	AUG	286.6	42.2	24.7	15.7	137.4	18.7	9.8	6.3	63.3	6.9	2.9	1.6	38.5	3.2	1.2	0.5
Asheville	SEP	344.2	34.6	15.0	8.1	166.9	15.8	6.7	3.6	78.6	6.5	2.6	1.4	49.2	3.4	1.3	0.6
Bakersfield	MAY	24.8	2.1	1.1	0.5	11.8	0.9	0.5	0.2	5.6	0.3	0.1	0.1	3.5	0.3	0.1	0.0
Billings	JUL	16.2	3.1	1.6	1.0	7.2	1.4	0.7	0.3	2.8	0.4	0.2	0.1	1.2	0.2	0.1	0.0
Boise	SEP	14.5	1.0	0.6	0.5	6.4	0.4	0.2	0.2	2.5	0.1	0.1	0.0	1.0	0.1	0.0	0.0
Boston	AUG	273.7	24.8	10.5	6.9	132.6	10.7	3.8	2.2	60.0	3.3	0.8	0.5	36.0	1.4	0.2	0.1
Cape Hatteras	SEP	262.1	42.7	27.9	20.3	125.9	19.7	12.7	8.7	58.1	8.4	4.8	3.3	35.8	4.3	2.3	1.5
Charleston	JUN	250.2	57.6	36.1	27.2	118.8	25.1	14.9	10.9	53.5	9.6	4.8	3.4	32.0	4.5	2.3	1.6
Cheyenne	JUL	38.5	8.9	5.0	3.0	16.9	3.6	1.6	0.9	6.7	1.0	0.2	0.1	2.8	0.2	0.1	0.0
Chicago	AUG	216.9	30.8	18.7	13.0	103.6	13.8	8.0	5.2	47.1	5.2	3.0	1.9	28.4	2.6	1.3	0.6
Denver	AUG	55.8	7.7	4.4	2.3	25.9	3.1	1.5	0.7	11.1	0.9	0.4	0.1	6.5	0.4	0.1	0.0
Ely	AUG	12.0	1.8	1.1	0.6	5.5	0.7	0.4	0.2	2.1	0.2	0.1	0.0	1.1	0.0	0.0	0.0
Grand Junction	JUL	17.9	1.6	1.1	0.9	8.0	0.5	0.2	0.2	3.2	0.1	0.1	0.1	1.7	0.1	0.0	0.0
Houston	MAY	219.5	50.5	30.9	21.6	105.7	22.4	13.2	9.0	49.2	8.8	4.8	2.9	29.9	4.4	2.0	1.2
Huntsville	JUL	206.2	49.5	32.3	23.4	96.4	21.6	13.6	9.3	42.8	8.1	4.4	2.8	25.8	3.6	1.7	0.9
Internat'l Falls	JUL	170.3	15.0	8.7	5.7	80.5	6.1	3.5	2.0	36.3	1.9	1.2	0.5	21.5	0.7	0.4	0.2
Key West	AUG	209.8	48.2	31.5	24.0	96.6	20.8	12.5	9.0	41.2	6.9	3.7	2.3	22.9	2.2	1.3	1.1
Lexington	JUL	258.2	43.0	29.2	20.9	123.6	19.2	12.7	8.6	56.9	7.3	4.1	2.9	34.3	3.3	2.2	1.4
Miami	JUN	276.0	61.0	42.6	33.1	128.7	26.2	17.8	12.9	55.7	9.6	5.9	3.9	33.1	4.1	2.4	1.6
Newark	AUG	247.9	34.5	17.0	12.1	117.9	14.4	6.4	4.1	54.1	4.7	1.9	1.3	32.7	2.0	0.6	0.3
New Orleans	AUG	273.3	69.4	47.4	34.0	128.0	31.2	19.9	13.5	56.5	11.7	6.5	4.0	33.0	5.4	2.7	1.5
NYC (Kennedy)	AUG	215.9	24.7	13.5	8.9	103.0	10.4	4.9	3.1	46.8	3.5	1.2	0.9	28.0	1.2	0.6	0.2
Oklahoma City	MAY	182.6	36.9	19.3	11.8	87.8	16.0	8.3	5.1	40.9	6.4	2.8	1.9	24.6	3.1	1.6	1.0
Omaha	JUL	169.8	23.2	14.0	10.1	79.5	9.7	5.7	3.9	35.0	3.0	1.7	1.1	21.0	1.4	0.7	0.5
Philadelphia	AUG	215.8	38.7	23.2	16.5	102.3	16.1	9.1	6.3	46.2	5.1	2.5	1.6	27.8	2.3	0.9	0.3
Phoenix	AUG	38.2	4.9	3.3	2.4	17.5	1.8	1.0	0.6	7.8	0.5	0.3	0.1	4.2	0.3	0.1	0.0
Pittsburgh	JUL	166.9	22.0	11.3	7.6	77.7	8.4	3.8	2.1	33.2	2.0	0.7	0.3	19.4	0.8	0.4	0.1
Raleigh	JUL	215.1	37.3	22.2	14.5	101.7	16.4	9.1	5.4	46.2	5.8	3.0	1.3	27.7	2.4	1.1	0.5
Rapid City	JUL	107.0	9.0	4.5	3.3	50.3	3.3	1.5	1.3	23.0	0.7	0.3	0.3	13.3	0.2	0.0	0.0
St. Louis	JUN	120.7	24.5	13.7	9.5	56.0	10.2	5.5	3.2	24.1	3.2	1.2	0.7	13.5	1.4	0.5	0.1
San Angelo	MAY	93.1	10.3	6.9	5.2	43.5	4.3	2.7	1.8	19.1	1.1	0.8	0.5	11.3	0.3	0.2	0.1
San Sebastian	SEP	233.2	69.9	49.7	37.9	111.6	31.8	22.0	16.4	51.7	12.8	8.6	6.1	31.4	7.1	4.4	2.6
Santa Maria	DEC	109.7	7.6	2.4	0.8	52.4	3.0	0.8	0.2	24.1	1.0	0.1	0.0	14.3	0.3	0.0	0.0
Seattle	AUG	144.8	1.6	0.5	0.2	69.2	0.5	0.1	0.0	31.2	0.0	0.0	0.0	19.1	0.0	0.0	0.0
Shreveport	MAY	178.1	46.1	27.8	24.3	85.2	21.4	12.4	10.4	39.7	9.0	4.8	4.1	24.4	4.7	2.5	2.0
Spokane	JUN	20.4	2.3	1.2	0.5	9.0	0.8	0.2	0.0	3.7	0.1	0.0	0.0	1.7	0.0	0.0	0.0
Tallahassee	AUG	301.8	74.9	51.1	39.9	142.3	32.8	21.5	16.8	64.2	11.9	7.4	5.1	38.2	5.7	2.8	1.9
Topeka	JUN	184.2	29.0	17.3	11.9	88.0	12.8	7.2	5.0	40.8	4.7	2.6	1.6	24.1	2.5	1.1	0.7
Urbana	JUL	159.6	34.5	23.1	16.6	73.1	12.4	7.3	4.9	31.0	3.2	1.6	0.8	17.6	0.7	0.2	0.1
Yuma	AUG	29.1	5.3	3.3	2.2	13.4	2.4	1.3	0.8	6.0	1.0	0.5	0.2	3.7	0.4	0.1	0.1

at dry locations in the western U.S., high altitude locations where freezing levels are lowest (generally in or around the Rocky Mountain states), or along the Pacific coast. Therefore, a satellite should be positioned to keep propagation paths highest in the eastern U.S.

An Air Force Geophysics Laboratory Technical Report due out by summer 1989 provides much more data and analyses on rain rates and attenuation outages. This report will enable a more detailed assessment of the probabilities and durations of satellite EHF communication outages due to attenuation by rain than has previously been available. Although only 42 locations were studied, they represent a variety of climatic regimes. The results at one location may provide a reasonable indication of rain-event characteristics at another location with similar climatic rainfall regimes. Further study of rain attenuation is planned at AFGL to determine spatial variability and ultimately an empirical model that can be used to estimate outages at most locations in the world.

Acknowledgement

The author is grateful to Jackie Davidson for typing this article.

REFERENCES

1. R.K. Crane (1980) "Prediction of Attenuation by Rain," IEEE Trans. Comm. COM-28, No. 9, 1717-1733.

2. P. Tattelman, and K.G. Scharr, (1983) "A Model for Estimating One-Minute Rainfall Rates," Journal of Climate and Appl. Meteor., 22 No. 9, 1575-1580.

3. P. Tattelman, and D.D. Grantham (1985) "A Review of Models for Estimating 1-min Rainfall Rates for Microwave Attenuation Calculations," IEEE Trans. Comm., COM-33, No. 4, 361-372.

4. P. Tattelman, and R.W. Knight (1988) "Analyses of 1-Min Rain Rates Extracted from Weighing Raingage Recordings," Journal of Appl. Meteorology, 27, No. 8, 928-938.

Table 4

Estimated Probability of at Least 3 System Outages Due to Rain for all Months at Boston, MA for the Indicated Durations and Fade Margins (Based on a Frequency of 30 GHz).

PROBABILITY OF AT LEAST 3 OUTAGES

		10-min Duration				20-min Duration				30-min Duration			
		Elevation Angle (in degrees)				Elevation Angle (in degrees)				Elevation Angle (in degrees)			
	Month	10	30	50	70	10	30	50	70	10	30	50	70
	JAN	*	*	*	*	*	*	*	*	*	*	*	*
	FEB	*	*	*	*	*	*	*	*	*	*	*	*
	MAR	.34	*	*	*	.03	*	*	*	*	*	*	*
	APR	.99	*	*	*	.88	*	*	*	.70	*	*	*
Freq = 30 GHz	MAY	.99	.36	*	*	.99	.02	*	*	.99	*	*	*
	JUN	.99	.82	.37	.09	.99	.16	.01	*	.99	.01	*	*
Fade = 15 dB	JUL	.99	.97	.64	.20	.99	.37	.03	*	.99	.05	*	*
	AUG	.99	.99	.72	.36	.99	.58	.05	.01	.99	.13	*	*
	SEP	.99	.99	.47	.10	.99	.63	.03	*	.99	.22	*	*
	OCT	.99	.50	.02	*	.99	.04	*	*	.99	*	*	*
	NOV	.99	*	*	*	.99	*	*	*	.97	*	*	*
	DEC	.19	*	*	*	.01	*	*	*	*	*	*	*
	JAN	*	*	*	*	*	*	*	*	*	*	*	*
	FEB	*	*	*	*	*	*	*	*	*	*	*	*
	MAR	.01	*	*	*	*	*	*	*	*	*	*	*
	APR	.64	*	*	*	.06	*	*	*	.02	*	*	*
Freq = 30 GHz	MAY	.99	*	*	*	.96	*	*	*	.73	*	*	*
	JUN	.99	.48	.09	*	.99	.02	*	*	.96	*	*	*
Fade = 20 dB	JUL	.99	.76	.24	.05	.99	.07	*	*	.94	*	*	*
	AUG	.99	.89	.36	.13	.99	.13	.01	*	.99	*	*	*
	SEP	.99	.78	.10	.03	.99	.10	*	*	.99	.01	*	*
	OCT	.99	.06	*	*	.99	*	*	*	.94	*	*	*
	NOV	.98	*	*	*	.67	*	*	*	.26	*	*	*
	DEC	*	*	*	*	*	*	*	*	*	*	*	*
	JAN	*	*	*	*	*	*	*	*	*	*	*	*
	FEB	*	*	*	*	*	*	*	*	*	*	*	*
	MAR	*	*	*	*	*	*	*	*	*	*	*	*
	APR	.04	*	*	*	*	*	*	*	*	*	*	*
Freq = 30 GHz	MAY	.98	*	*	*	.55	*	*	*	.14	*	*	*
	JUN	.99	.25	*	*	.92	*	*	*	.54	*	*	*
Fade = 25 dB	JUL	.99	.45	.06	.02	.95	*	*	*	.59	*	*	*
	AUG	.99	.55	.15	.03	.99	.02	*	*	.93	*	*	*
	SEP	.99	.17	.04	*	.99	*	*	*	.96	*	*	*
	OCT	.99	.01	*	*	.71	*	*	*	.27	*	*	*
	NOV	.71	*	*	*	.20	*	*	*	.03	*	*	*
	DEC	*	*	*	*	*	*	*	*	*	*	*	*

* < .01

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

AD-A204 661

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release Distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFGL-TR-89-0037	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Air Force Geophysics Laboratory 6b. OFFICE SYMBOL *(If applicable)* LYA	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS *(City, State, and ZIP Code)* Hanscom AFB Massachusetts 01731-5000	7b. ADDRESS *(City, State, and ZIP Code)*
8a. NAME OF FUNDING/SPONSORING ORGANIZATION 8b. OFFICE SYMBOL *(If applicable)*	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS *(City, State, and ZIP Code)*	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62101F PROJECT NO. 6670 TASK NO. 09 WORK UNIT ACCESSION NO. 14

11. TITLE *(Include Security Classification)*

Satellite EHF Communication Design Considerations Due to Attenuation by Rain

12. PERSONAL AUTHOR(S)
Paul Tattelman

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT *(Year, Month, Day)*	15. PAGE COUNT
Reprint	FROM ____ TO ____	1989 May 1	5

16. SUPPLEMENTARY NOTATION Reprinted from: 1989 Proceedings of the 35th Annual Technical Meeting of the Institute of Environmental Sciences, 1-5 May 89 Anaheim, California

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Rain; Attenuation; EHF Communications; Rainfall Rate; Satellite Communications

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The increasing use of Extra High Frequencies (EHF) planned for satellite communications has prompted studies on the impact of signal attenuation by rain. Rain is the major environmental cause of communication outages at frequencies above 10GHz. One-minute rainfall rates are considered to be the most practical time-averaged rate for use in attenuation models to estimate outages. Data on one minute rain rates are very scarce, but a new data set of these rates was extracted for a 10-year period at 42 U.S. locations. This paper presents analyses of the duration and frequency of one-minute rain rates, their impact on EHF communications, and resulting design considerations.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL PAUL TATTELMAN	22b. TELEPHONE *(Include Area Code)* 617-377-2981	22c. OFFICE SYMBOL AFGL/LYA

DD Form 1473, JUN 86 *Previous editions are obsolete.*

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified